Virtual Experiments in Marine Bioacoustics: Whales, Fish, and Anthropogenic Sound

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Grant Number: N00014-09-1-0611

LONG-TERM GOALS

This is a programmatic effort has three long-term goals. The first is to combine medical tomography (primarily CT-scans) with finite-element modeling software (developed by Dr. Petr Krysl), and tissue property measurements (conducted by Dr. Robert Shadwick), to simulate the bioacoustic interactions between selected anthropogenic sounds and fish anatomy. This method has already been successful in providing insights on such phenomena in some marine mammals (Cranford et al. 2008a, b). The second long-term goal is to improve and refine our ability to measure tissue samples by building a portable device that we can take into the field in order to measure physical properties from fresh tissue samples. The third and final goal is to continue the development of the finite element modeling software to incorporate new tools and techniques that will allow us to expand the taxonomic breadth of our vibro-acoustic research.

OBJECTIVES

Although we have considerable experience employing our methodology with marine-mammal specimens, primarily toothed whales, acquiring, scanning, analyzing, and interpreting modeling results from fishes presents new challenges. Our immediate objectives involve acquiring specimens of selected species as soon as possible so as to quickly recognize any new challenges arising from differences between fish and cetacean species. We have already acquired three postmortem specimens from local (San Diego, CA) fishmongers and have also acquired two high-resolution fish CT-scans

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Virtual Experiments In Marine Bioacoustics: Whales, Fish, And Anthropogenic Sound**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Quantitative Morphology Consulting, Inc.,2674 Russmar Dr,San Diego,CA,92123**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

from DIGIMORPH at the University of Texas at Austin. We were fortunate to be given a large, euthanized White Seabass (actually a marine sciaenid croaker, *Atractoscion nobilis*) from Hubbs-Sea World Research Institute (HSWRI) in Carlsbad, CA. Table 1 identifies the fish species that we have begun to study and some of their pertinent characteristics.

Our second proximal objective is to standardize and improve our ability to measure tissue properties; primarily Bulk Modulus and sound speed in samples from various tissues.

APPROACH

Fish populations comprise important parts of marine and freshwater ecosystems as well as being the foundation of considerable human nutrition, industry, and economy. They also represent a wide diversity of forms and sensory systems. This variability along with the complications imposed by boundary conditions makes physical experimentation of limited scope, whereas properly-validated modeling may allow greater flexibility in evaluating possible effects of selected anthropogenic sounds on a broad spectrum of fishes.

As with previous work (Cranford et al., 2008a, b) we acquire medical tomography data sets (primarily CT-scans) and take them apart into their anatomical components (called “segmenting”). The physical specimen is scanned and dissected, after which the physical properties of the various tissue components are measured, particularly density and elasticity, which are important to sound propagation. These measured properties and their locations in the specimen are combined within the computer software to produce a virtual specimen or model. This model is placed into a 3-dimensional virtual environment, constructing an experimental test bed through which we simulate sounds propagated through the virtual specimen and reveal the interactions between the sound and the anatomy.

We recognize that the U.S. Navy is concerned with possible impacts on marine fishes. Our team benefits from the expertise of Dr. Tony Hawkins of Aberdeen, Scotland, a world authority on hearing and sound production in fishes. His involvement helps guide our selection of fish species, at times selecting better-studied freshwater forms that are primarily intended for empirical validation of our methods using independent data sets.

WORK COMPLETED

In the first seven months of this project we have acquired, scanned, and processed the specimens listed in Table 1. We have developed an effective apparatus for holding large fish specimens (the White Seabass was about one meter in total length) upright but uncompressed (the gas bladder is a critical component in many fishes’ hearing anatomy). We acquired White Seabass soon after HSWRI euthanized the specimen by overdose with a standard fish anesthetic as part of their ongoing research with this species. Within a few hours, we placed the fish in a net frame, transported it to the University of California, San Diego Medical Center and collected a complete set of CT scans using the newest model scanner from General Electric (see Figure 1, Appendix A). Defining and separating the various anatomic structures from the image data is a process known as Segmentation. Segmentation of the fish specimens requires expertise in fish anatomy and is being largely accomplished through the efforts of Carl Schilt.

Work on the development of new tools for the vibroacoustic software continues apace in Dr. Krysl's lab and we will soon introduce the capability to change the scale of element size during simulations. This will allow us to reduce computational overhead for large, whole-animal data sets.

Table 1 – Six fish species have been acquired and CT-scanned for this study to date. The specimens CT-scanned at the University of Texas at Austin were kindly provided by Dr. John Lundberg (catfish) and Dr. George Lauder (Blugill). Yellowtail = Seriola lalandi; Silver Carp = Hypopthalmichthys molotrix; White Croaker = Genyonemus lineatus, Channel Catfish = Ictalurus punctatus, Bluegill = Lepomis macrochirus; White Seabass = Atractoscion nobilis

Family	Species	Habitat	Soniferous	Bladder	Audiology	Importance	Source
Carangidae	Yellowtail	Marine	Probably not	No	None	Sport and commercial	San Diego
Cyprinidae	Silver carp	Freshwater	Unknown	Yes	One study	Invasive species	San Diego
Sciaenidae	White croaker	Marine	Yes	Yes	Atlantic	Primarily sport	San Diego
Ictaluridae	Channel catfish	Freshwater	Unknown	Yes	Yes	Commercial and sport	U of Texas
Centrarchidae	Bluegill	Freshwater	Unknown	Yes	No	Sport	U of Texas
Sciaenidae	White seabass	Marine	Probably	Yes	Atlantic	Low population	HSWRI

RESULTS

Our results are, at this early stage, are preliminary and we have include two examples to illustrate the nature of what we are doing. They can be seen in Appendix A, Figures 1 and 2. The segmentation process is ongoing with the White Seabass and other specimens. One example (Appendix A, Figure 1) shows some results of that segmentation, some important structures in the front third of the meter-long White Seabass (*Atractoscion nobilis*).

Some preliminary modeling results have been produced for the Yellowtail (*Seriola lalandi*) where interactions between the swimbladder and incident sound can be seen.

The second example, (Appendix A, Figure 2) shows data reported by Dr. Robert Shadwick, University of British Columbia). The measurement of density and elasticity are inherently important to sound propagation in any medium. This is an important step in our model-building process.

IMPACT/APPLICATION

There is growing concern with possible harmful effects of human-generated sound on fishes (recently reviewed by Popper and Hastings 2009a, b). The diversity of fishes (Helfman 1997) as well as their varied mechanisms of hearing (Popper and Fay 1999) and the tremendously varied effects of depth in the water, water depth, nearby boundaries, and other boundary conditions (Schilt, 2007) makes direct *in situ* experimentation unavoidably daunting whereas our validated modeling effort will enable a time-and-cost effective means of answering questions about the effects of selected levels of selected sounds under selected conditions.

As we progress we will endeavor to acquire, segment, and model using an array of ecological and commercially valuable species including herrings, tunas, codfishes, drums, Pacific rockfishes, and flatfishes.

RELATED PROJECTS

This project is an outgrowth of the methodology we have developed over the past eight years (see examples in Soldevilla et al. 2005, Krysl et al. 2006, and Krysl et al. 2007). We are currently using the same basic methods to study interaction between toothed whale anatomy and selected sounds.

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Appendix A

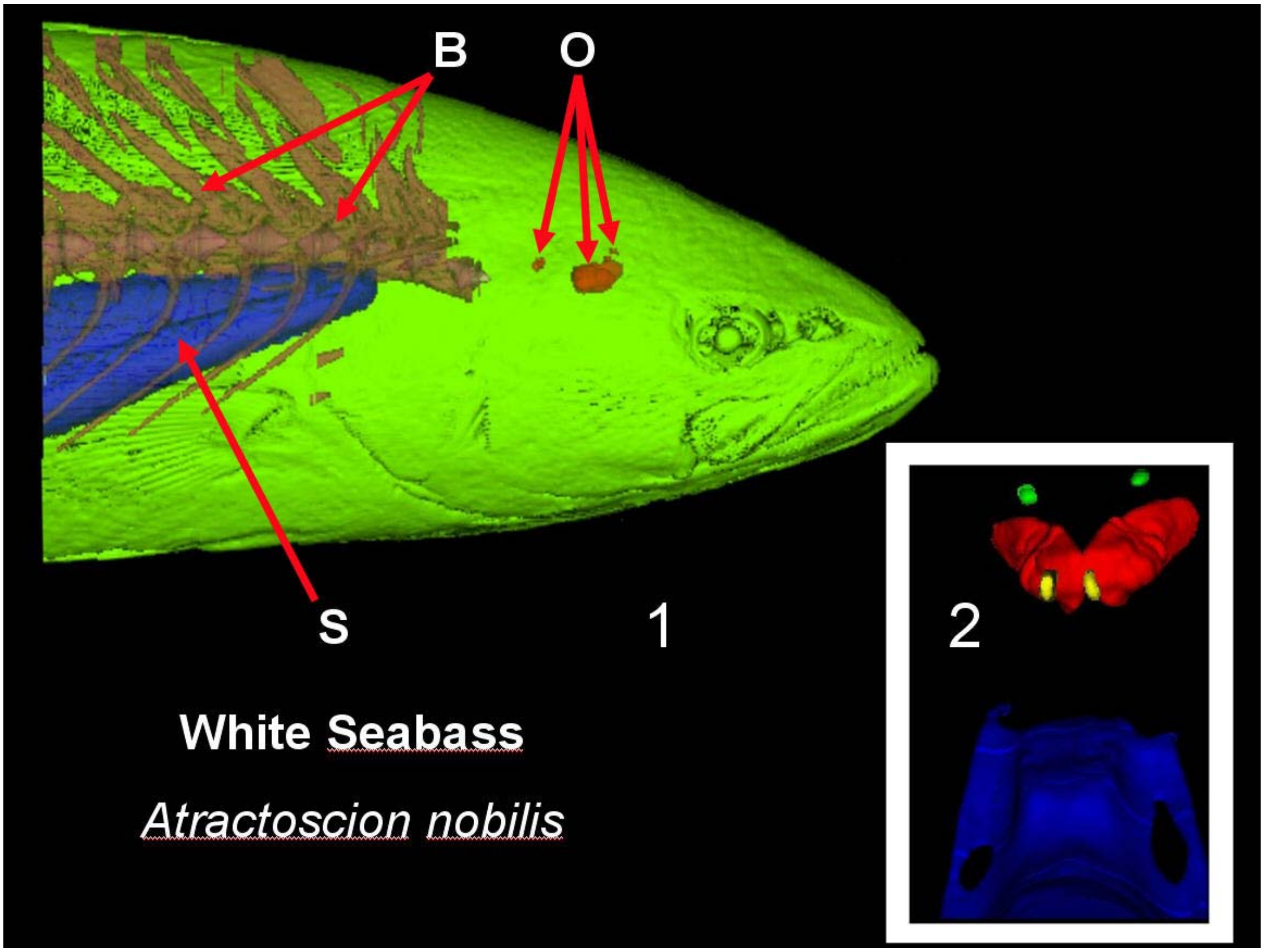

Figure 1 – The primary image (1) shows some of the structures segmented from the CT-scan volume taken from a one-meter White Seabass (Atractoscion nobilis). The labeled structures are; B = Vertebral column and other associated bony elements, O = Otoliths, S = Swimbladder. The inset image (2) shows a posterodorsal view of: Anterior swimbladder in blue, Sacular otoliths (saggita) in red; Lagenar otoliths (asterici) in yellow, and lagenar otoliths (lapilli) in green.

Appendix A

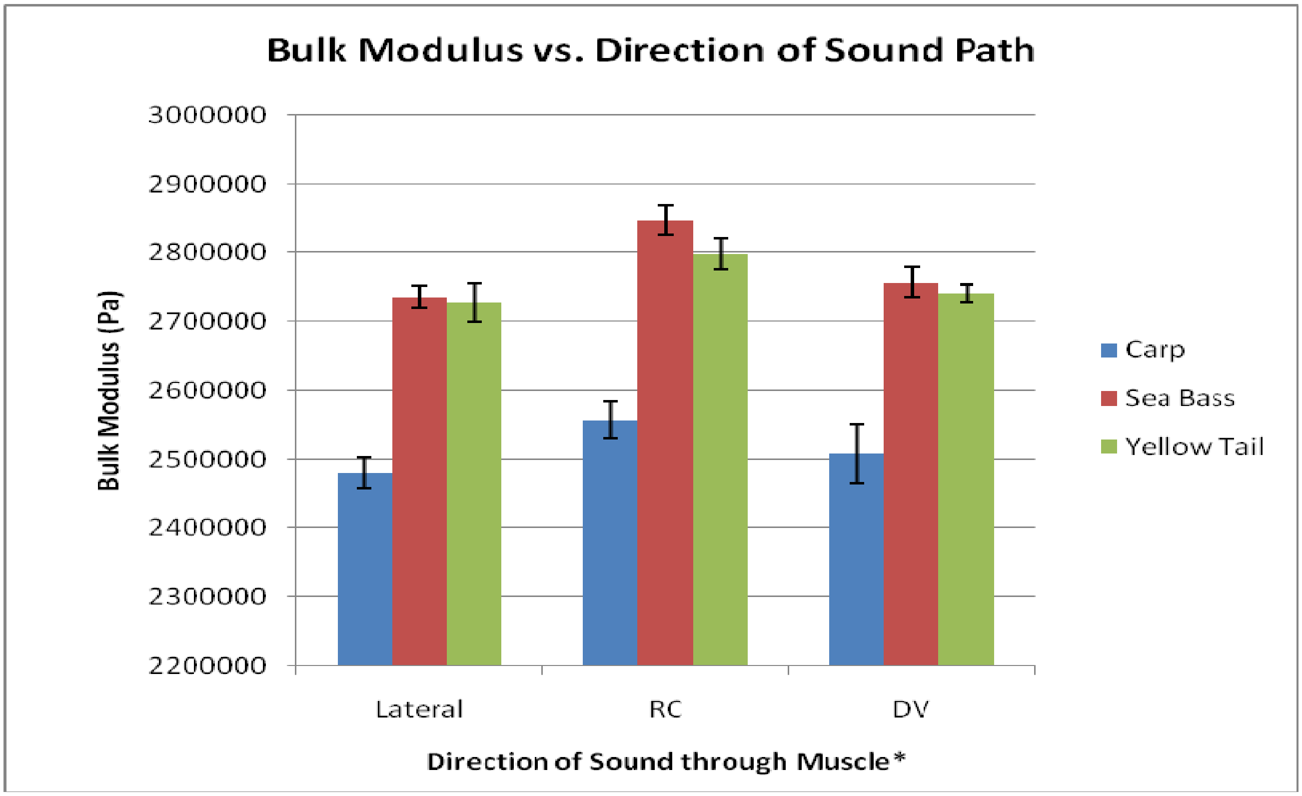

Figure 2 – This graph summarizes the relationship of the measured bulk modulus of the muscle of three species, the Silver Carp (Hypopthalmichthys molotrix), the White Seabass (Atractoscion nobilis) and the Yellowtail (Seriola lalandi). Carp muscle had an oily texture, and lower sound speed and density. In all fish samples, sound speed was the highest in RC (rostrocaudal) direction. Carp muscle also had the lowest elastic modulus out of the 3 species.